# USING SILICON POWER RECTIFIERS

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RECENT months have seen a marked improvement in the availability in the United Kingdom of relatively low-cost silicon power rectifiers. Silicon diodes rated at 250 mA mean output current and 1000 volts peak inverse voltage (p.i.v.) are being offered by BULLETIN advertisers for less than 9s., while those with a 400 volts p.i.v. rating can be purchased for about 3s. 6d.

Unfortunately, however, many members have found to their cost that it is all too easy to destroy these components—together, often enough, with the associated mains transformer. This is not due to any inherent unreliability of silicon diodes, but far more often because insufficient attention has been paid to fundamental design problems. The correct operation of these rectifiers has been touched upon several times in *Technical Topics* but it is felt that the subject is of sufficient importance to justify a fuller review of how these breakdowns occur, and how they can be avoided.

### Why use Silicon Rectifiers?

First, consider why it is worth bothering about these rectifiers. After all, we have been using thermionic and selenium metal rectifiers happily enough for years, and have them well tamed. And, at present prices, a well-designed power supply with silicon diodes is not likely to prove cheaper than with other types of rectifiers.

Neither valve nor metal rectifiers can meet the definition of the ideal rectifier, that is to say, a device which offers zero impedance to current flow in one direction (forward resistance) and infinite impedance in the other (reverse resistance). It can be shown simply (though painfully) by touching the envelope that a valve rectifier has a fairly high forward resistance—the high operating temperature of the envelope derives from the power which is being wastefully dissipated inside it. The valve rectifier must also be considered as having a limited life. Metal rectifiers have appreciable forward resistance, which is why cooling fins are fitted. A metal rectifier takes up considerable space; furthermore the forward resistance tends to increase with age. Thus both valves and metal rectifiers occupy appreciable cabinet space, require special mounting in the form of a valve socket or mounting clips, need good ventilation, and generate a great deal of heat which may cause such effects as oscillator drift, or the deterioration of rubber wiring and electrolytic capacitors.

Germanium and silicon junction rectifiers are much nearer the ideal; they have very low forward resistance and high reverse resistance. Of the two, germanium has the lower forward resistance and is used for currents above about 1 amp. Silicon, though slightly less efficient, has a wider temperature range, and is generally used for currents of less than 1 amp., and increasingly in the 1-10 amp. range. Because of the low forward resistance, very little heat is dissipated. The smaller silicon diodes have no need of cooling fins, can be made as compact as small resistors, and can be similarly supported directly in the wiring. As with metal rectifiers, no heater supplies are needed. All these points add up to a highly efficient rectifier with very real advantages for many applications over all the earlier types of power rectifiers.

What then are the snags? The main problems arise partly from the relatively low peak inverse voltages which can be withstood by diodes* manufactured at the present state of the art and partly from the inherent high efficiency of the unit. Because the forward resistance is so low, the silicon diode can readily pass destructively high currents if excessive voltages are applied even for a short period (this compares unfavourably with the average selenium rectifier which is usually rated for unlimited instantaneous peak currents). Recent silicon rectifiers can withstand transient surges much better than earlier types, but nevertheless precautions are still necessary.

A frequent cause of previously unexplained silicon diode failures in this country and elsewhere is now known to be the momentary voltage surges which occur at irregular intervals on the electric supply mains; these overvoltages are usually of too short duration to affect electric appliances or lamps.

We thus have two main design problems: in the first place we must make sure that under normal working conditions we are keeping well within the p.i.v. rating of each diode; secondly, and just as important, we must do something to limit the high voltage and current surges that inevitably appear in power supplies at the moment of switching and during mains overvoltages.

### Calculating P.I.V. Ratings

The first step when considering the design of a power supply using silicon diodes is to calculate the basic peak inverse voltages which will appear across each diode. Fig. 1 shows the situation for the most commonly used circuits (these theoretical figures ignore transformer and rectifier voltage drops, etc. but this is of little practical consequence).

Consider the case of the very popular bi-phase or full-

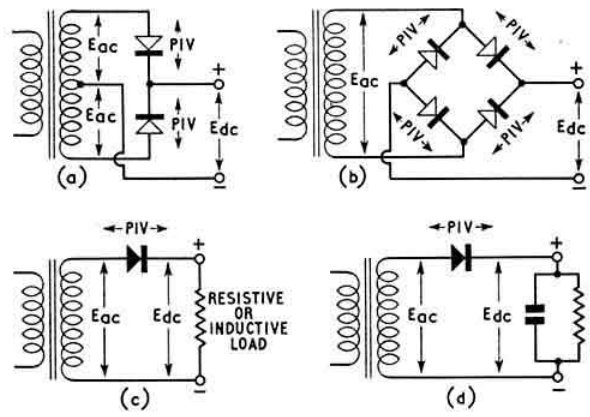


**Fig. 1. Fundamental power supply relationships.**

**(a) Bi-phase or full wave rectifier. P.I.V. $\simeq$ 2·8 × $E_{ac}$ or 3·14 × $E_{dc}$. $E_{dc} \simeq 0{\cdot}9 \times E_{ac}$. With a capacitive load, the actual value of d.c. output voltage will be affected by the value of the reservoir capacitor in relation to the d.c. load.**

**(b) Full wave bridge rectifier. P.I.V. (each diode section) $\simeq$ 1·4 × $E_{ac}$ or 1·57 × $E_{dc}$. $E_{dc} \simeq 0{\cdot}9 \times E_{ac}$ (see note above).**

**(c) Half-wave rectifier with inductive or resistive load. P.I.V. $\simeq$ 1·4 × $E_{ac}$. $E_{dc} \simeq 0{\cdot}45 \times E_{ac}$.**

**(d) Half-wave rectifier with capacitor load. P.I.V. $\simeq$ 2·8 × $E_{ac}$. $E_{dc} \simeq 0{\cdot}9 \times E_{ac}$ (see note above).**

* In fact the p.i.v. rating of a single unit or disc of a selenium rectifier is generally a good deal less than that of a silicon diode; but whereas selenium rectifiers are usually rated as a complete stack of discs, we are thinking here of individual silicon diodes (though stacks of diodes are also marketed).

wave circuit (Fig. 1(a)). The p.i.v. across each leg of the rectifier is approximately equal to $2\sqrt{2}$ (about 2·8) times the alternating voltage (measured in r.m.s.) across each half of the transformer secondary winding. Thus with a 350-0-350 volt transformer, the p.i.v. across each rectifier section will be roughly 2·8 × 350 volts, which is 980 volts. To provide a reasonable margin of safety, it will be advisable for each section to have a p.i.v. of about 1200 volts. A single diode with this rating would tend to be rather expensive; in practice we might well decide to use three 400 p.i.v. types in series (we could use one diode rated at 400 p.i.v. in series with one of 800 p.i.v. but, as we shall see later, there are some disadvantages in mixing different types of diodes). Thus, for this power supply, at least six 400 p.i.v. diodes would be needed in two series-strings of three diodes each.

In this calculation it has been necessary to distinguish between the a.c. input to the rectifiers and the theoretical d.c. output. This is because the multiplication factor to obtain the p.i.v. from the theoretical d.c. output is 3·18, appreciably higher than the 2·8 used. This can be important since we often tend to think in terms of a 350 volt power supply, rather than of one using a 350-0-350 volt transformer, forgetting that the two are not the same.

In order to obtain a rating of 1200 volts p.i.v. we cannot just connect three 400 p.i.v. diodes in series. The resultant p.i.v. would be 1200 volts only if the reverse resistance of each diode were precisely the same. Actually the voltage distribution across the three diodes resembles that of a potentiometer comprising three different value resistors—the higher the reverse resistance of any particular diode, the greater will be its share of the total inverse voltage. Unfortunately, the reverse resistance of current types of silicon diodes vary appreciably. A range of up to 3 to 1 has been quoted even for the same make and type of diode, while much greater discrepancies can be found among mixed types and makes. Since a limit is reached when any one of the diodes has a reverse voltage of 400 volts, the three 400 p.i.v. diodes are likely to have a combined series rating well below 1200 volts unless elaborate steps have been taken to match them.

Fortunately this problem can be overcome by connecting an equalizing resistor across each diode (as should be done incidentally for series-connected VR-tubes and electrolytic capacitors). The value of the resistor must be relatively small compared with the reverse resistances of the diodes. The peak inverse voltages are then shared almost equally between the diodes despite any differences in the diodes themselves. A typical value would be 150,000 ohms. These resistors will, of course, allow a certain amount of a.c. to bypass the diodes but this forms only a small part of the ripple current.

The above notes clearly show the advisability of always using equalizing resistors with a series string of diodes unless there is a great margin of safety. It is true that one still sees many published designs in which this precaution is omitted; the designers have either been lucky in their choice of diodes, or are depending upon the conservatism of makers' ratings, or have trouble in store! Even with equalizing resistors it is advisable not to operate series-connected diodes right up to their full p.i.v. ratings if this can be avoided. A good safety margin will give you something in hand to meet unavoidable current and voltage surges.

As an alternative to resistors, equalizing capacitors may sometimes be recommended for this purpose, forming an a.c. potentiometer.

### Surge Limiting

With any rectifier having a low forward resistance (e.g. silicon or mercury-vapour rectifiers) consideration must be given to the effect of operating into a capacitive load such as that presented by the reservoir capacitor of the conventional ripple filter. At the moment of switching on, the reservoir capacitor represents an almost direct short-circuit across the output of the rectifier. Additionally, if the value of the capacitor is high, then large peak currents will flow during the relatively short duty-cycle of the rectifier. The peak current which will flow at switch-on will depend upon the precise moment in the a.c. cycle when the switch is closed; the worst possible conditions occur when the switch closes exactly at the peak of the sine wave. A silicon rectifier has no protective warm-up time so that it is possible for a heavy surge of current to flow into the reservoir capacitor.

As with mercury vapour and other low impedance rectifiers, this problem can be largely solved by using a choke-input rather than a capacitive-input, ripple filter; this change will also improve voltage regulation, though at the cost of some lowering of d.c. voltage output. However, a choke is a bulky and fairly expensive component and there are many applications where this solution is inconvenient. In such circumstances it is highly advisable to fit a surge limiting resistor between the rectifier and the reservoir capacitor, even though this results in some loss of rectification efficiency and the generation of additional heat. An acceptable value for a surge limiting resistor is roughly 30 ohms per diode: thus with a series string of three diodes, a suitable value resistor would be 100 ohms.

Transient voltages are generated whenever a magnetic component (such as a transformer or choke) is energized or de-energized. For example, transient voltages of a peak amplitude several times that of normal can be generated through the sudden interruption of current by switching.

Generally, we look upon urban and National Grid supply mains as well regulated, varying perhaps by a few per cent during peak consumption periods. It comes as something of a surprise to find that recent investigations have shown that in fact our mains supplies misbehave violently from time to time. G5CD has drawn our attention to an article* which discloses the results of a recent Mullard enquiry into industrial and domestic mains supplies in different parts of the United Kingdom. For example, at Dudley, Worcs., during a period of six weeks the following substantial overvoltages were recorded: 35 of 20-40 per cent above normal; 7 of 40-70 per cent; and 1 of over 100 per cent. At Cheam, Surrey, during a period of 12½ weeks, recorded overvoltages amounted to 27 of 20-40 per cent; 4 of 40-70 per cent; and 8 of 70-100 per cent. Such transients may last only a few microseconds and have little effect on valve rectifiers (except some large gas-filled types). But, since a 100 per cent overvoltage on 230 volt mains is equivalent to 460 volts r.m.s. or 650 volts peak, it will be appreciated that these voltage surges can all too easily result in semiconductor failures, even in otherwise well designed power supplies.

The built-in protection against voltage transients varies with the type and make of silicon diodes—some 800 volt p.i.v. types have transient inverse voltage ratings of around 1350 volts, but in many of the earlier diodes the margin is a good deal less. For the amateur designer, who will seldom have any reliable information on the overvoltages likely to appear on his particular mains supply, and who may not even have full makers' information on the diodes he wishes to use, a practical safeguard is to leave the most generous possible safety margins that are economically practical.

There are various circuit methods of reducing the effects of transients arising from switching surges and mains overvoltages. G2BVN passes along the information that one British manufacturer advises the use, with 800 p.i.v. diodes, of transient damping devices across the rectifier output and also across the transformer secondary: each of these damping devices consists of an 0·1 μF capacitor in series with a 1 K ohms resistor (here again watch a.c. ratings).

### Temperature Effects

The characteristics of junction rectifiers, like those of other

* "Portable Mains Overvoltage Detector" *Mullard Technical Communications*, Vol. 6, Nr. 51, September, 1961.

semiconductor devices, are sensitive to changes in temperature. Although silicon diodes can be used at temperatures well above the boiling point of water (100° C), the maximum safe d.c. output current falls quite rapidly with increasing temperature. Just as many transmitter valves have to be " derated " with increasing frequency, so the maximum output of silicon diodes must be reduced with increasing ambient temperature. Some diodes are rated at 25° C or 35° C, others at 70° C so this point has to be watched.

The extent of the derating necessary can be quite severe; for example, a unit rated for full output at 35° C may need to be derated by 25 per cent at 55° C and by no less than 60 per cent at 100° C, although the figures vary a little with type. Thus a 250 mA diode might have to be restricted to about 100 mA if required to operate at a high temperature. In such cases, it is always advisable to check with makers' literature.

The amount of heat generated in the rectifier itself is low, so that it should usually be possible to ensure that the diodes run cool. They should be mounted so that a reasonable amount of cool air can reach all outside surfaces; they should

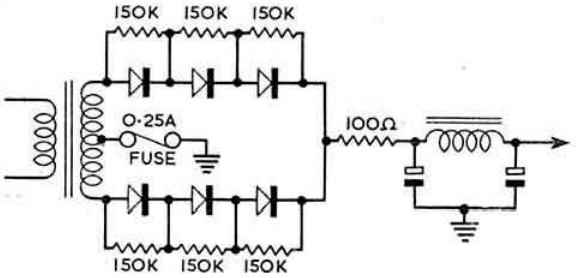


**Fig. 2. Typical 350 volt power supply using series connected silicon diodes illustrating some of the precautions discussed in the test.**

be kept away from heat producing valves and components. The running temperature of any equalizing or surge-limiting resistors can be kept low by fitting generously rated types. Try to ensure that the diodes are not mounted in currents of warm air coming from valves, etc.

### Fusing

It is the unfortunate tendency of silicon diodes when breaking down to short- rather than to open-circuit. This, of course, greatly increases the danger that a fault in one diode will be followed by others and so endanger the transformer and other components in the power pack. To what extent can these hazards be avoided by protective fuses?

The typical power supply of Fig. 2 shows a fuse in the lead to the transformer centre-tap. Such a fuse is very useful in providing protection against a short-circuit across the load being fed by the power supply. It must be readily admitted, however, that it will provide only limited protection against other faults, for the following reasons:

If one diode in a string short-circuits, the p.i.v. across the remaining ones increases, and these in turn are likely to fail. Regardless whether or not the fuse blows, this process may continue until all six diodes have broken down; should these all short-circuit then an effective short-circuit appears across the total transformer secondary winding and this may burn out.

Better protection for the transformer is afforded by connecting a fuse in the transformer primary circuit. This however cannot usually be done with a conventional cartridge fuse since one rated low enough to offer adequate protection is likely to blow during switching on surges. Surge-proof Mag-Nickel delay fuses are likely to be more satisfactory. But for maximum protection what is really needed is some device which would immediately disconnect the unit on the failure of one diode.

### Miscellaneous Points

The connection of two silicon diodes in parallel in order to increase the maximum current rating should be avoided if possible; this is because the forward resistance of individual diodes may differ appreciably so that the current load will not be shared equally between them. Should parallel operation be decided upon, the units should either be derated by about 30 per cent or individual equalizing resistors of upwards of about 10 ohms should be connected in series with each diode.

Most makers warn users to take care to avoid damage to the hermetic sealing and to avoid overheating of the junction when connecting diodes into circuit. At least $\frac{1}{4}$ in. of connecting lead should be left leading straight out of the unit before any bend or soldered connection is made in the wire. When soldering it is advisable to grip the lead between the rectifier and the joint with a pair of pliers to provide a heat shunt.

### Conclusions

Many of the problems discussed above apply to a much lesser degree for low-voltage, medium current supplies for which germanium and silicon diodes are ideally suited. The low forward resistance is also of particular value for voltage doubling and for obtaining good regulation. In higher voltage supplies, these diodes—as we have seen—have both advantages and disadvantages compared with alternative types of rectifiers; the disadvantages however are steadily being overcome. Provided care is taken in design, long and reliable operation can be expected of silicon diodes. The inherent efficiency, low temperature operation, small size and ease of mounting ensure that these rectifiers will play an increasingly important role in amateur radio.

## CONTESTS DIARY

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|---|---|
| March 16–18 | A.R.R.L. DX Contest (c.w.) (see page 360, January 1962) |
| March 24–25 | CQ WW S.S.B. Contest (see page 394, February, 1962) |
| April 7–8 | Low Power Contest (For rules see page 454) |
| April 7–8 | International Millenium SP Contest (c.w,) |
| April 14–15 | International Millenium SP Contest (Telephony) |
| April 14–15 | R.E.F. Contest (Telephony) |
| April 15 | D/F Qualifying Event (London) (see page 454) |

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| April 28—29 | — | V.E.R.O.N. PACC (c.w.). |
| April 29 | — | D/F Qualifying Event (Birmingham). |
| May 5—6 | — | V.E.R.O.N. PACC (Telephony). |
| May 5—6 | — | U.S.S.R. DX Contest. |
| May 6 | — | 144 Mc/s Field Day. * |
| May 13 | — | D/F Qualifying Event (Oxford). |
| May 26—27 | — | First 420 Mc/s Contest. |
| May 27 | — | D/F Qualifying Event. |
| June 2—3 | — | National Field Day. (see page 359) |
| June 16—17 | — | 70 Mc/s Contest. |
| June 24 | — | D/F Qualifying Event (Newbury). 1250 Mc/s Tests. |
| July 7—8 | — | V.H.F. National Field Day. |
| July 15 | — | D/F Qualifying Event (Wirral). |
| August 10—11 | — | European Fox-Hunting Championships (Ankaran, Yugoslavia) |
| September 1—2 | — | Region 1 I.A.R.U. V.H.F. Contest. |
| September 9 | — | D/F National Final. |
| September 16 | — | Low Power Field Day. |
| October 7 | — | R.A.E.N. Rally. |
| October 20—21 | — | Second 420 Mc/s Contest. |
| October 27—28 | — | R.S.G.B. 7 Mc/s DX Contest (Phone). |
| November 3—4 | — | R.S.G.B. 7 Mc/s DX Contest (c.w.) |
| November 10—11 | — | Second 1·8 Mc/s Contest. |
| December 1—2 | — | R.S.G.B. 21/28 Mc/s Telephony Contests. |

**To coincide with I.A.R.U. Region 1 V.H.F. Contest dates.*